

Characterizing Ammonia Emissions from Swine Farms in Eastern North Carolina – Part II. Potential Environmentally Superior Technologies for Waste Treatment

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Species: Swine

Use Area: Manure Storage, Manure Treatment

Technology Category: Anaerobic digestion, aerobic treatment, solid separation/gasification, solid separation/off site removal

Air Mitigated Pollutants: Ammonia, Odor, Pathogens

Description:

The need for developing environmentally superior and sustainable solutions for the management of animal waste is vital for the future of animal farms in North Carolina, the U.S. and the world. In addressing that need, the North Carolina Attorney General initiated the development, implementation, and evaluation of environmentally superior swine waste management technologies (ESTs) that would be appropriate to each category of hog farms in North Carolina. The agreements define “Environmentally Superior Technology or Technologies” as any technology, or combination of technologies that (1) is permissible by the appropriate governmental authority; (2) is determined to be technically, operationally, and economically feasible for an identified category or categories of farms (to be described in a technology determination); and (3) meets the following performance standards:

- Eliminates the discharge of animal waste to surface waters and groundwater through direct discharge, seepage, or runoff;
- Substantially eliminates atmospheric emission of ammonia;
- Substantially eliminates the emission of odor that is detectable beyond the boundaries of the parcel or tract of land on which the swine farm is located;
- Substantially eliminates the release of disease-transmitting vectors and airborne pathogens; and
- Substantially eliminates nutrient and heavy metal contamination of soil and groundwater.

Program OPEN (Odor, Pathogens, and Emissions of Nitrogen) was initiated as an integrated study of the emissions of ammonia, odor and odorants, and pathogens from potential ESTs for swine facilities. Its main purpose was to evaluate potential ESTs that have been developed and implemented under an agreement between the North Carolina Attorney General and the participating companies that own approximately 10% of the swine farms in North Carolina, employing the conventional lagoon and spray technology (Aneja et al., 2008 a,b). Under this program, ESTs implemented at selected swine facilities were evaluated to determine if they would be able to substantially reduce atmospheric emissions of NH₃, odor, and pathogens. This study focuses on the emissions of nitrogen in the form of NH₃ from different components/processes involved in hog waste handling and treatment, including waste storage lagoons, hog houses, and spray fields at eight selected EST sites. These are described below in the following format; name of the farm where the potential EST was employed, type of technology, and brand name where applicable.

(1) Barham Farm – in-ground ambient temperature anaerobic digester/energy recovery/greenhouse vegetable production system; (2) BOC # 93 Farm -Up-flow biofiltration system - EKOKAN ; (3) Carrolls Farm- Aerobic Blanket System - ISSUES-ABS; (4) Corbett # 1 Farm - Solids separation/gasification for energy and ash recovery centralized system-BEST; (5) Corbett # 2 Farm – solid separation/ reciprocating water technology- ReCip; (6) Vestal Farm- Recycling of Nutrient, Energy and Water System-ISSUES-RENEW; (7) Goshen Ridge Farm (Solids Separation/nitrification-denitrification/soluble phosphorus removal/solids processing system (Super Soils); (8) Red Hill Farm (‘Closed Loop’ Swine Waste Treatment System). The first six EST sites contain anaerobic lagoons as part of their system, however EST # (7) and (8) do not contain anaerobic lagoons as part of their system. These potential ESTs were evaluated during two seasons (cool and warm), and the results are compared and contrasted with data from two conventional LST swine farms (Moore Farm and Stokes Farm).

The conventional lagoon and spray technology (LST), is the current system used in North Carolina to manage pig waste. It consists of anaerobic lagoons to store and biologically treat pig waste (~99.5% liquid). Effluent from the lagoons is sprayed on surrounding crop fields as a nutrient source. Four distinct components and associated processes of LSTs release NH_3 to the atmosphere: (1) production houses, (2) waste storage and treatment systems such as lagoons, (3) land application through injection or spraying, and (4) biogenic emissions from soils and crops.

Mitigation Mechanism:

(1) Barham Farm – in-ground ambient temperature anaerobic digester/energy recovery/greenhouse vegetable production system. Mitigation of emissions occurs predominately due to anaerobic catabolism of volatile organic compounds as well as physical containment (preventing emissions) due to the impermeable cover component of the in-ground digester. Post anaerobic treatment the digested effluent is further process in biological trickling filters thus enhancing biological nitrification of ammonia. This potential EST has an in-ground ambient digester comprised of a covered anaerobic waste lagoon. The primary lagoon was covered by an impermeable layer of 40 mm thick high-density polypropylene that prevented gaseous methane and other gases and odor from escaping into the atmosphere during the digestion process. Methane gas that is produced during the digestive process was extracted and burned into a biogas generator to produce electricity. Heat from the generator was captured and used to produce hot water that was used by the farm in its production activities. Effluent from the digester (covered lagoon) flowed into a storage pond, with a surface area of 4,459 m^2 . This storage pond was formerly part of the primary anaerobic lagoon before the digester was built. A portion of this effluent was further treated via biofilters, whose purpose was to convert ammonium to nitrate in the effluent. This nitrified effluent was then used to flush out the hog production facilities, and the excess effluent was channeled into the larger overflow pond, with a surface area of 19,398 m^2 . A heavy polymer baffle separated the overflow and storage ponds. The overflow pond was used to store rainwater and overflows from the storage pond. Water from the overflow pond was also pumped into a nitrification biofiltration system where the nutrients in the treated effluent were used to fertilize vegetables grown in greenhouses adjacent to the swine production facility.

(2) BOC # 93 Farm -Up-flow biofiltration system – EKOKAN. Mitigation of emissions occurs predominately due to aerobic catabolism of volatile organic compounds and biological nitrification of ammonia within the aerated biofilter. The EKOKAN waste treatment system consists of solids/liquid separation and biofiltration of the liquid with upflow aerated biological filters. Five finishing barns are connected to the waste treatment system, and the barn pits are emptied automatically in sequence. Wastewater from the barn pits is released to a solids separation unit. Coarse solids are separated from the wastewater using a screen separator (TR Separator). After the solids/liquid separation process, the liquid is pumped to a 40,000-gallon equalization tank. Liquid flows from the equalization tank by gravity and passes through first-stage and second-stage aerated biofilters connected in series (two sets). Wastewater flows upward through the biofilters, and air is supplied at the bottom of each biofilter with blowers. The biofilter tanks are covered, and air and any excess foam from the aerated treatment are routed through PVC pipes to exit points over an anaerobic lagoon. The biofilters are backwashed periodically to remove excess biosolids. Treated effluent from the biofilters flows by gravity to a storage basin, with a portion of the treated effluent being recycled to the solids separation basin, from which it is pumped to the equalization tank, which has a surface area of 28.3 m^2 . Water is pumped from the storage basin to the barns to refill the pits. At this site, the anaerobic lagoon that receives manure from 10 barns was partitioned using plastic curtains into three sections, with one section much larger than the other two. The larger section receives manure from five barns not connected to the EKOKAN treatment system. One of the smaller sections receives any overflow from the solids separation basin, the separated solids, and the backwashed biosolids that are removed from the biofilters. This is known as the biosolids lagoon and has a surface area of 3229.2 m^2 . The other small section receives the treated effluent from the biofilters. This is known as the treated effluent lagoon and has a surface area of 1614.6 m^2 .

(3) Carrolls Farm- Aerobic Blanket System - ISSUES-ABS. Mitigation of emissions occurs predominately due to aerobic catabolism of volatile organic compounds and biological nitrification of ammonia at the surface of the aerobic blanket. The waste stream in the proposed EST flows from the houses to a primary anaerobic lagoon equipped with the Aerobic Blanket System (ABS). This is known as the ABS lagoon and has a surface area of 3304.8 m^2 . The ABS consists of a fine mist of treated swine waste that is applied every 15 minutes to the surface of the anaerobic lagoon. During both evaluation periods, only half of the anaerobic lagoon was being treated by the ABS. The treated swine waste arises from an aeration treatment that takes place in an adjoining water-holding structure (aerobic digester). Waste from the anaerobic lagoon flows into an aerobic digester (IESS aeration system). This is referred to as the west side of the aerated lagoon and has a surface area of 5068.8 m^2 . This portion of the basin is sectioned off with a plastic barrier. The aerated waste eventually flows into the sectioned-off portion of the aeration treatment basin. This is known as the east side of the aerated lagoon, and has a surface area of 6010.2 m^2 . The waste is then used to flush the animal houses, and supplies the treated water for the ABS. During the first evaluation period, the IESS aeration system was not functioning and treated waste for the ABS was derived by using two aeration treatment tanks. For the second evaluation, the aeration treatment basin was operating as designed. Only waste from finishing houses 5 – 13

flowed into the ABS-equipped anaerobic lagoon. Waste from the remaining farrow and weaning houses flowed into a separate lagoon. These houses and their accompanying lagoon were not included in the evaluation of the EST.

(4) Corbett # 1 Farm - Solids separation/gasification for energy and ash recovery centralized system-BEST. Mitigation of emissions occurs predominately due to physical containment and recovery of the solids which are removed from the site for further processing (gasification) – this process reduces the substrate available for biological synthesis of volatile organic compounds. Manure flushed from the barns flows first to a collection pit, then to an above-ground feed tank, and then to a screw press separator on a raised platform. The separator has a screen with .25 millimeter openings. The liquid that flows through the screw press separator screen flows to a second feed tank, which has a surface area of 27.1 m², then to two tangential flow gravity settling tanks sited parallel to each other. Each tangential flow settling system consists of a 2.2-meter diameter tank with a cone bottom followed by a 1.2-meter diameter sludge thickening tank, also with a cone bottom. Tangential flow in the first tank causes solids to concentrate in the center of the tank and settle down to the bottom. This settled slurry is then pumped to the second tank for sludge thickening. For about 10 minutes every hour the settled slurry from the second tangential flow settling tank is pumped back to the tank that feeds the screw press separator, where the settled slurry is combined with the flushed manure that is being pumped to the screw press separator. The treated waste and any overflow go to a stabilization and treatment pond, which has an area of 8291.9 m².

(5) Corbett # 2 Farm – solid separation/ reciprocating water technology- ReCip. Mitigation of emissions occurs predominately due to physical containment and recovery of the solids which are removed from the site for further processing – this process reduces the substrate available for biological synthesis of volatile organic compounds. In addition, the reciprocating wetland cells enhance biological catabolism of volatile organic compounds and support the process of nitrification / denitrification thus reducing ammonia emissions. The ReCip encompasses two cells, or treatment basins, filled with media (proprietary technology), that would alternately drain and fill on a cyclic basis. The draining and filling cycles created aerobic, anaerobic, and anoxic conditions within the cells, providing both biotic and abiotic treatment processes to promote nitrification and denitrification. The treatment process was preceded by a solids separation step. The solid waste and the treated liquid waste went into individual lagoons, which had surface areas of 2,601 m² and 2717 m², respectively. The ReCip project at the evaluation time was designed to treat only the liquid portion of the swine waste.

(6) Vestal Farm- Recycling of Nutrient, Energy and Water System-ISSUES-RENEW. Mitigation of emissions occurs predominately due to anaerobic catabolism of volatile organic compounds as well as physical containment (preventing emissions) due to the impermeable cover component of the in-ground digester. Post anaerobic treatment some of the digested effluent is further process in an aeration basin thus enhancing biological nitrification of ammonia. The RENEW System employs a mesophilic digester as well as aeration and wastewater filtering and disinfection systems. This project also incorporated a microturbine generator. For this system, the waste first flows from the pig barns to equalization and concentrator tanks, which serve to produce a thickened liquid. This liquid then flows to a mesophilic digester. The digester, which operates at a temperature of 95 degrees F, produces biogas, which is used to fuel the microturbine generator. The generator produces electricity, which is sold and used on the electric power grid. The waste stream then flows to a polishing storage basin, which has a surface area of 22,636.0 m², then to an aerobic digester, also called a nitrification pond, which has a surface area of 1880.6 m². A portion of the waste stream then flows back to the polishing storage basin, where it is used to flush the pig barns and is sprayed on crop land if necessary. The remaining portion of the waste stream flows through a filtration system. The filtration system consists of sand carbon filters and reverse osmosis. The water is then disinfected using ozonation and ultraviolet light. Filtered and disinfected water is then returned to the pig barns, where it is used as drinking water for the pigs.

(7) Goshen Ridge Farm (Solids Separation/nitrification-denitrification/soluble phosphorus removal/solids processing system (Super Soils)). Mitigation of emissions occurs predominately due to physical containment and recovery of the solids which are flocculated and mechanically concentrated and removed from the site for further processing – this process reduces the substrate available for biological synthesis of volatile organic compounds. In addition, an aeration component enhances biological catabolism of volatile organic compounds and supports the process of nitrification / denitrification thus reducing ammonia emissions. The treatment system employed at Goshen Ridge Farm, known as Super Soils, treats the liquid portion of the waste. The liquid treatment begins with separation of the solid and liquid portions of the waste stream. Solids separation is accomplished using polyacrylamide, a flocculating agent. The liquid portion of the waste stream flows between tanks in a circulating loop undergoing denitrification as a result of anaerobic activity in one tank, and nitrification through the use of concentrated nitrifying bacteria in the second tank under aerobic conditions. Nitrogen is removed from the waste stream during this stage of the process. The liquid then flows to a settling tank, where phosphorus is removed through the addition of calcium hydroxide and a dewatering bag system. Calcium phosphate, which has value as a fertilizer, precipitates out during this process, providing a value-added product. During phosphorus removal, the pH of the liquid is raised to 10.5 using lime, which precipitates the

soluble P and disinfects the effluent. Roughly 80 percent of the liquid is recycled through the hog houses, while 20 percent is used to irrigate crop fields.

(8) Red Hill Farm ('Closed Loop' Swine Waste Treatment System). Mitigation of emissions occurs predominately due to physical containment and recovery of the solids which are removed from the site for further processing – this process reduces the substrate available for biological synthesis of volatile organic compounds. In addition, this system has a chemical sanitation component which reduces the microbial population that may be contributing to the synthesis of volatile organic compounds. The EST at Red Hill farm was provided by 'Environmental Technologies'. This EST is described as a "closed-loop" system, and its primary objective is to treat the liquid fraction of the waste in such a way that it can be used both for flushing the hog barns and for hog drinking water. This could eliminate the need for the traditional hog waste lagoon. A flush system is used for removing the manure from the barns, which, prior to installation of the treatment system, flushed the waste into a lagoon. The first step in the closed loop process is collection of the waste in an "equalization" or buffering tank. The waste in the tank is continuously pumped to an inclined separator where the solids are collected and further treated. The liquid collected from the separator is injected with a polymer flocculant and sanitizer/disinfectant and pumped into a settling tank, where flocculated solids collect at the bottom over a period of approximately four hours.

Most of the liquid fraction from the settling tank is returned to the hog barns for re-use as flush water. When the flush tanks are full, however, excess water is pumped to a tertiary treatment system. This system provides filtration and aeration and is housed in a septic tank. The treated water is blended with well water to achieve a dissolved solids content that is consistent with human drinking water standards for use as hog drinking water. Solids from the settling tanks are combined with the solids from the inclined separator for further treatment.

Applicability:

The environmental performance studies for all of these systems were conducted on swine production facilities in North Carolina. While the applicability of some of these systems may be appropriate for "deep pit" systems, they were predominately designed for "plug flow" and higher volume "flush" systems characteristic of North Carolina swine production systems; for the purpose of this evaluation study all of the systems should be considered applicable to typical North Carolina systems. At each environmentally superior technology and conventional site, the monitoring of ammonia emissions was limited to about two two-week periods, representing both a warm and a cool season. It was suggested that the estimated emissions from an environmentally superior technology for each measurement period be compared with the estimated emissions from conventional sites. However, since measurements at different sites were made at different times of the year, environmental conditions are likely to be different at different sites, even during a representative warm or cool season. Thus, there is a need for accounting for these differences in our relative comparisons of the various alternative and conventional technologies.

A rational basis for this adjustment for somewhat different environmental conditions is the development of a statistical-observational model based on multiple regressions. This is developed between ammonia emissions and measured environmental parameters at the two conventional sites. Such a comparison does not require highly uncertain extrapolations of emissions at EST sites beyond the two measurement periods. It also provides a sound basis for ranking the various ESTs based on their comparisons with conventional sites for each of the warm and cold seasons. Relationships between NH_3 flux and lagoon temperature, pH, total Kjeldahl nitrogen (TKN), and total ammoniacal nitrogen (TAN), as well as certain environmental parameters are examined in Aneja et al. (2008 a,b). Over a relatively wide range of lagoon temperatures ($\sim 2^\circ\text{C}$ to $\sim 35^\circ\text{C}$) and lagoon - air temperature differences that were observed during the fall and winter field campaigns at both conventional farms. The multiple regression equation based on flux measurement data from two conventional farms is given as:

$$\text{Log}_{10}F = 3.8655 + 0.04491(T_1) - 0.05946(D). \quad (1)$$

Here, F denotes the average $\text{NH}_3\text{-N}$ emission from the conventional lagoon in $\mu\text{g min}^{-1}/1000 \text{ kg-lw}$, where T_1 is the lagoon temperature in $^\circ\text{C}$, and D is a hot-air variable that is equal to zero if lagoon is warmer than air, but is equal to $\Delta T = T_a - T_1$ when $T_a > T_1$ and T_a is air temperature in $^\circ\text{C}$ at 2m height. This statistical-observational model was used to estimate the projected $\text{NH}_3\text{-N}$ flux from lagoons at the LST baseline farms to compare with the measured $\text{NH}_3\text{-N}$ flux from water-holding structures at an EST site, for the average values of T_1 and D observed at the latter.

Aneja et al. (2008 a,b) describes the development of the statistical-observational model in more detail. Estimated ammonia emissions from animal houses at a potential EST were compared to the estimated ammonia emissions from similar houses at a conventional farm (either Moore Farm-tunnel ventilated, or Stokes Farm-naturally ventilated), depending on the type of the house ventilation used at the EST farm, for the same season. Both EST emissions and conventional NH_3 emissions were normalized by nitrogen excretion rate (E) for the farm, and are called %E. Based on

the nitrogen mass balance equation with given animal feed information, nitrogen excretion rate (E) in unit of kg-N wk^{-1} ($1000 \text{ kg-}lw)^{-1}$) was determined using the following equation:

$$E = \frac{F_c \times N_f \times (1 - e_r)}{\bar{w}} \times 1000, \quad (2)$$

where F_c is the feed consumed ($\text{kg pig}^{-1} \text{ wk}^{-1}$), N_f is the fraction of nitrogen content in feed, e_r is the feed efficiency rate (ratio of average gain of nitrogen to nitrogen intake) (PigCHAMP, 1999), and \bar{w} is the average live animal mass (kg/pig). Nitrogen excretion and $\text{NH}_3\text{-N}$ emissions at each farm was calculated in the same units (kg-N wk^{-1} ($1000 \text{ kg-}lw)^{-1}$), thus, %E represents the loss rate of ammonia from a source, as a percentage of N-excretion rate. A potential EST was evaluated by comparison of %E value from the EST (% E_{EST}) farm to %E value from a baseline conventional farm (% E_{CONV}), and percent reduction of $\text{NH}_3\text{-N}$ can be estimated as

$$\% \text{ reduction} = \frac{(\% E_{CONV} - \% E_{EST})}{\% E_{CONV}} \times 100 \quad (3)$$

Such percentage reductions can be estimated, separately for water-holding structures, animal houses/barns, *etc.*, as well as for the whole EST farm. An algorithmic flow diagram for the evaluation of NH_3 emissions from water holding structures at the EST farms is shown in Figure 1.

To calculate the total % reduction, the sum of projected and measured emissions was taken for the water-holding structures and barns. These numbers were used to calculate total % reduction using the same process that was applied individually for water-holding structures and barns. Table 1 shows the summary of the total NH_3 emissions measured for six of the eight EST farms (farms that contained anaerobic lagoons as part of their system), along with the projected emissions from the LST farms, and the % reduction values for their evaluation of potential N reduction. Five out of six farms showed varying amounts of % reductions in NH_3 emissions for both experimental periods. One of the five ESTs showed an appreciable % reduction in NH_3 emissions for both periods. The technology employed at Corbett # 1 had the highest % reductions of 71.8 and 66.0 for the warm and cool seasons, respectively. However, based on our evaluation results and analysis, and available information in the scientific literature, the evaluated alternative technologies may require additional technical modifications to be qualified as unconditional EST relative to ammonia emissions reductions.

Two potential ESTs with no conventional anaerobic lagoon component were evaluated to determine if they would substantially reduce atmospheric emissions of ammonia at the hog facilities and meet the performance standards as compared to estimated or projected emissions from the conventional lagoon and spray technology used at two selected hog farms in two different (warm and cool) measurement periods. Table 2 shows the summary of the water-holding structure NH_3 emissions measured from EST farms, projected emissions from the water-holding structures at the conventional (LST) farms, and % reduction values for their evaluation of potential N reduction.

Both farms showed substantial reductions in NH_3 emissions from their water-holding structures. The Environmental Technologies closed loop system had the largest reductions, with reduction of 99.4% and 99.98% for the cool and warm season, respectively. Super Soils technology had a reduction of 94.7% in the cool season, and 99.0% in the warm season. This study did not address the potential reductions in odor and pathogens that were evaluated by other scientists in the OPEN project (Williams, 2006). Under the conditions reported herein these two potential ESTs meet the criteria established for ammonia emissions as described for ESTs (Williams, 2004).

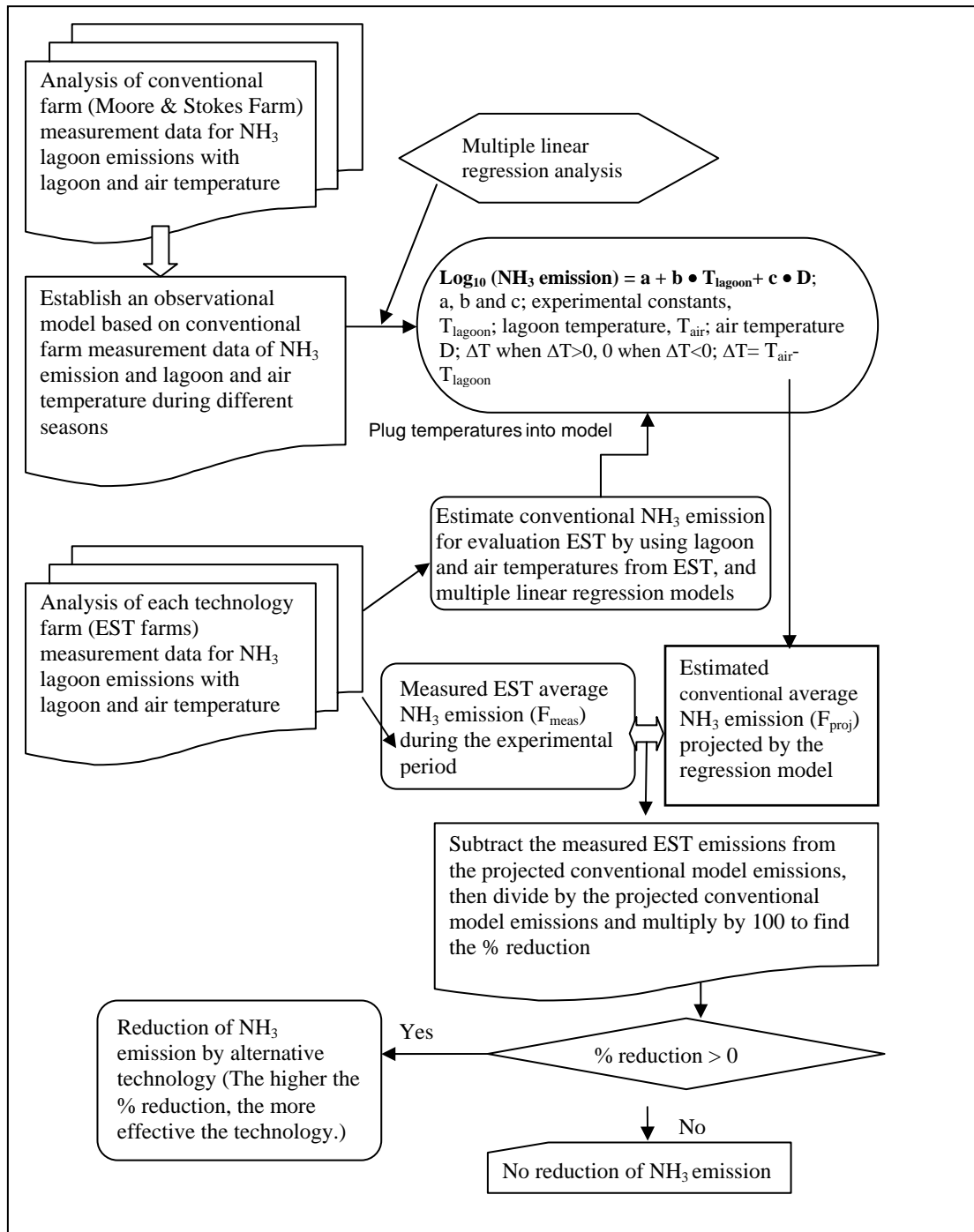


Figure 1. Algorithm flow chart for evaluation of EST emissions from water-holding structures.

Limitations:

Most of the candidate ESTs reported herein represent animal waste treatment systems that have undergone experimental development and performance testing. Some of the systems are continuing to be developed to improve efficiency of operation and reduce capital, operational and maintenance costs. Based on the work reported to date, most limitations are associated with operational feasibility and / or costs (see below). It is recommended that producers considering the candidate ESTs for implementation carefully assess available objective information related to the environmental performance, operational and economic feasibility of the referenced ESTs.

Cost:

Ten year annualized costs for the candidate ESTs are reported in Table 2.

Technology Summary:

The need for developing environmentally superior and sustainable solutions for managing the animal waste at commercial swine farms in eastern North Carolina has been recognized in recent years. During two-week long periods in two different seasons (warm and cold), NH₃ fluxes from water holding structures and NH₃ emissions from animal houses or barns were measured at eight potential EST sites: (1) Barham Farm – in-ground ambient temperature anaerobic digester/energy recovery/greenhouse vegetable production system; (2) BOC # 93 Farm -Up-flow biofiltration system - EKOKAN ; (3) Carrolls Farm- Aerobic Blanket System - ISSUES-ABS; (4) Corbett # 1 Farm - Solids separation/gasification for energy and ash recovery centralized system-BEST; (5) Corbett # 2 Farm – solid separation/ reciprocating water technology- ReCip; (6) Vestal Farm- Recycling of Nutrient, Energy and Water System-ISSUES-RENEW; (7) Goshen Ridge Farm (Solids Separation/nitrification-denitrification/soluble phosphorus removal/solids processing system (Super Soils);(8) Red Hill Farm ('Closed Loop' Swine Waste Treatment System). EST sites (7) and (8) did not contain anaerobic lagoons as part of their system. The ESTs were compared with similar measurements made at two conventional Lagoon and Spray Technology (LST) farms (Moore Farm and Stokes Farm). A flow-through dynamic chamber system and two sets of open-path FTIR spectrometers measured NH₃ fluxes continuously from water holding structures and emissions from housing units at the EST and conventional LST sites. In order to compare the emissions from the water-holding structures at the ESTs with those from the lagoons at the conventional sites under similar conditions, a statistical-observational model for lagoon NH₃ was used. A mass balance approach was used to quantify the emissions. All emissions were normalized by nitrogen excretion rates. Six of the eight ESTs that contained an anaerobic lagoon as part of the system did not substantially reduce ammonia emissions and therefore require additional technical modifications to be qualified as unconditional EST relative to ammonia emissions reductions. Two of the eight ESTs did not contain an anaerobic lagoon component. Both of these farms showed substantial reductions in NH₃ emissions from their water-holding structures. Under the conditions reported herein these two potential ESTs meet the criteria established for ammonia emissions as described for ESTs (Williams, 2004).

Table 1. Summary of NH₃ emissions from the EST farms and reduction during the experimental periods.

EST Farms	Sampling Periods	Emission Sources	Measured emission (F _{meas}) kg-N/wk/1000kg-lw	%E _{ST}	%E _{EST} (WHS + house)	EST avg. lagoon temp (°C)	EST avg. D (°C)	Conventional Lagoon emission (model/estimated) kg-N/wk/1000kg-lw (F _{proj})	% E _{CONV} (lagoon + house)	% reduction
Barham	Apr. 2002	WHS	0.31	18.8	39.4	17.2	0.7	0.4	11.3	-11.9
		house	0.34	20.6				1.05	23.9 [†]	
BOC # 93	Nov. 2002	WHS	0.07	4.0	31.7	14.2	0.3	0.31	9.7	2.5
		house	0.49	27.7				0.89	22.8 ^a	
Carrolls farm	Apr.03	WHS	0.23	8.2	28.4	18.5	0.7	0.46	14.3	23.5
		house	0.57	20.2				0.89	22.8 ^a	
		WHS	0.58	11.0	35.6	28.6	0.3	1.38	38.9	43.3
Corbett # 1 Farm	Jun.03	house	1.29	24.6				1.05	23.9	
		WHS	0.21	5.4	30.5	15.0	0.0	0.34	10.6	8.7
Corbett # 2 farm	Mar-Apr.04	house	0.98	25.1				0.89	22.8 ^a	
		WHS	0.23	5.6	33.4	29.1	0.0	1.50	42.2	49.5
Corbett # 1 Farm	Jun-Jul.04	house	1.15	27.8				1.05	23.9	
		WHS	0.33	5.6	8.3	21.8	0.2	0.69	19.4	71.8
Corbett # 2 farm	Oct.03	house	0.16	2.7				0.25	10.0 [*]	
		WHS	0.12	5.1	5.4	9.3	0	0.19	5.9	66.0
Vestal	Dec.03	house	0.008	0.3				0.25	10.0 [*]	
		WHS	0.35	11.0	14.8	14.9	1.6	0.28	8.7	20.9
Vestal	Sep.03	house	0.12	3.8				0.25	10.0 [*]	
		WHS	0.81	18.0	28.9	24.1	1.0	0.78	22.0	9.7
Vestal	Dec.03	house	0.49	10.9				0.25	10.0 [*]	
		WHS	0.39	7.8	9.2	14.8	0.6	0.32	10.0	54.0
Vestal	Mar. 04	house	0.07	1.4				0.25	10.0 [*]	
		WHS	1.07	19.6	33.3	28.5	0.3	1.36	48.3	31.1
Vestal	August,04	house	0.75	13.7				0.25	10.0 [*]	

[†]NH₃ emission measured from barns at tunnel (fan) ventilated conventional farm (Moore farm) during October 2002. ^{*}NH₃ emission measured from barns at tunnel (fan) ventilated conventional farm (Moore farm) during February 2003. ^aNH₃ emission measured from barns at naturally ventilated conventional farm (Stokes farm) during January 2003. WHS = Water-holding structures

Table 2. Summary of total NH₃ emissions from the EST farms and % reduction during experimental periods.

EST Farms	Sampling Periods	Measured emission (F _{meas}) kg-N/wk/1000kg-lw	%E _{EST}	EST avg. lagoon temp (°C)	EST avg. D (°C)	Conventional lagoon emission (model/projected) (F _{proj}) kg-N/wk/1000kg-lw	%E _{CONV}	% reduction
Goshen Ridge	Apr-May.03	0.02	0.6	17.2	0.7	0.40	11.3	94.7
	Feb-Mar .04	0.004	0.1	14.2	0.3	0.31	9.7	99.0
Red Hill	Mar-Apr .05	0.003	0.06	14.9	0.5	0.32	10.0	99.4
	July-Aug. 05	0.0006	0.01	31.6	0.0	1.95	54.9	99.98

Table 2. Ten year annualized costs for the candidate ESTs

EST Farms	10 year annualized cost (\$ per 1000 lbs. steady state live weight per year)
Barham	\$89
BOC # 93	\$342
Carrolls	\$95
Corbett # 1	\$115 - \$147
Corbett # 2	\$143
Vestal	\$126
Goshen Ridge	\$400*
Red Hill	\$137

For detail information see: (Williams, 2006. Table 8a, page 58)

* A Phase 2 generation of this technology has shown that the unit cost has been reduced to \$300 or less. (see Williams, 2007)

Additional Resources:

Additional and detail information re materials and methods and cost information is available at http://www.cals.ncsu.edu/waste_mgt/

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